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TEXTILE DYEING LABORATORY RESEARCH REPORT NO. 14

DEVELOPMENT OF ELECTROMAGNETICALLY SHIELDED PORTABLE SHELTERS

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Materials

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FOREWORD

Interference of electromagnetic radiation from radar transmitters with electronic computing devices may introduce errors into computations which are used in conjunction with artillery and missile firing. Conditions of field operation may require that computing equipment be housed in shelters that can be moved as a military situation requires. This report discusses the development of portable shelters which incorporate in their design the feature of shielding electromagnetic radiation of microwave frequencies. The shielding is also necessary in order to protect operating personnel from the high intensity energy which is characteristic of some of the newer developments in radar.

The cooperation of personnel in both the Tentage and Equipage Branch and the Textile Dyeing Laboratory Branch was essential. In addition to the authors, Messers Conway W. Weikert, Allen N. Moody, Chester I. Moses, and William T. Burns made important contributions to the study.

FRANK J. RIZZO
Chief
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CONTENTS

ABSTRACT

~~This report describes~~ the various steps in the development of a design for portable shelters which afford shielding from microwave radiation. The shelters were designed to house electronic computing devices and operating personnel in proximity to radar transmitters. Shielding from microwave radiation is necessary to prevent interference and consequent malfunction of electronic equipment and to insure safety to operating personnel.

Reflectivity to microwave radiation was measured for several flexible materials. A silverized nylon fabric and aluminized polyester film were found to be more effective in reflecting the energy than the other materials studied.

A scale model of the shelters was constructed of materials suggested for use in the final design. The model was submitted for evaluation to a field type test to determine levels of attenuation within the shelters when illuminated with microwave radiation at three frequencies. It was found that leakage at over-lapping joints limited attenuation to an average of about 40 db for L band, 33 db for "s" band, and 26 db for "x" band.

Designs are suggested for improving the closure at over-lapping joints which should raise the level of attenuation.

Part I: Electromagnetic Shielding Material for Shelters

Alvin O. Ramsley

1. Introduction

The Quartermaster Research and Engineering Command was requested through a transfer of funds from Rome Air Dvelopment Command, to construct four shelters for housing operational electronic equipment. In the field this equipment is often used in proximity to radar transmitters, which may interfere with the proper functioning of the electronic equipment in the shelters. The Air Force had requested that "maximum electrical shielding" be provided to assure that interference from the radar transmitter be held to sufficiently low levels.

Radar signals consist of microwave radiation which comprises the region of the electromagnetic spectrum between radio waves and infrared radiation. Portions of the spectrum, e.g., infrared, visible, x-ray, and radio waves, have become recognized as distinct fields of study. However, all electromagnetic radiation obeys the same basic laws of propagation, refraction, reflection and differ from one area to another only in frequency and wavelength and the manner in which the radiation interacts with matter. Delineation of the various regions has come about primarily because different methods are required for their production and detection. These different techniques stem from the mechanisms by which radiation in various wavelength regions of the spectrum interacts with matter.

A summary of the differences between various spectral regions in regard to wavelength and the manner of interaction with matter is shown in Table I. Since considerable over-lapping of wavelengths from one region to another and interactions in mechanisms occur, the tabulation is only approximate.

Table I: Influence of Various Spectral Regions

Spectral Region	λ (cm)	Response of Matter
Gamma rays	10^{-8}	Nuclear vibration
X-rays	10^{-8} - 10^{-6}	Inner electrons
Ultraviolet	10^{-6} - 4×10^{-5}	Valence electrons
Visible	4 - 7×10^{-5}	Valence electrons
Near infrared	7×10^{-5} - 2.5×10^{-4}	Overtones of molecular vibration
Infrared	2.5×10^{-4} - 2.5×10^{-3}	Molecular vibration
Far infrared	2.5×10^{-3} - 5×10^{-2}	Molecular rotation
Microwave	5×10^{-2} - 1200	Molecular rotation and polarisation

Table II lists the various frequency bands for radar commonly in use. By comparison the frequency of visible light is 400 - 800 mega-megacycles per second.

Table II: Designations and Approximate Spectroscopic Properties of Various Radar Bands

Band	Frequency (mc/sec)	Wavelength (cm)	Alternate Designations
P	25 - 39	770 - 1200	10 meter band
L	39 - 1550	20 - 770	1 meter band
S	1550 - 5200	5.8 - 20	10 centimeter band
X	5200 - 11,000	2.7 - 5.8	3 centimeter band
K	11,000 - 30,000	1 - 2.7	1 centimeter band
millimeter	30,000 - 600,000	0.05 - 1	millimeter band

Radar signals, which operate in the microwave region of the electromagnetic spectrum, travel in straight lines at the speed of light. They may be reflected, absorbed, or transmitted at the surface of the shelter in a manner analogous to visible light. Only that portion of the incident radiation which is transmitted can interfere with instruments within the shelter. Consequently, shielding will be possible only if the signal is absorbed or reflected. In discussions with personnel of the Engineer Research and Development Laboratories it soon became apparent that shielding of electronic equipment could best be accomplished by reflection. Use of absorbing systems would be uneconomical in terms of money, weight, and bulk. This part of the report consists of an examination of a number of materials with respect to reflectivity at various frequencies of microwave radiation.

2. Experimental observations

At our request reflectances of a series of fabrics and related materials were made by ERDL personnel at 3 cm and by the group at the Naval Research Laboratory at 10 cm. These are summarized in Table III.

Table III: Reflectance (%) at Two Wavelengths and Direct Current Resistance of Seven Fabric Systems

	Fabric	3 cm*	10 cm*	d. c. resistance**
1.	Swift fabric - silver on nylon	95	100	0.8
2.	Carbon black on cotton sateen	<1	<1	$>10^7$
3.	Carded cotton sateen, OG 107	<1	<1	$>10^7$
4.	Cotton sheeting with vacuum deposited aluminum	<1	<1	$>10^7$
5.	Cotton drill with "milium"	<1	<1	$>10^7$
6.	Vacuum aluminized mylar	95	100	4.0
7.	Aluminum foil bonded to paper and nylon mesh	95	100	0.1

* Reflectance relative to a solid sheet of iron as 100%.
** Ohms per square.

Reflectances of 12 fabric systems were measured at three frequencies 1000, 3000, and 10,000 megacycles by Pickard and Burns, Needham, Massachusetts under contract with the [redacted] Command. These data represent measurements of microwave energy reflected from a sample illuminated at normal incidence. Table IV summarizes the data obtained on the 12 samples.[1]

Table IV: Microwave Reflectivity of Twelve Fabric Systems at Three Frequencies

Sample No.	Description	Percent Power Reflected "L" BAND 1,000 mc/s	"S" BAND 3,000 mc/s	"X" BAND 10,000 mc/s
1.	Aluminized Mylar on Poplin.	100	100	100
2.	Aluminum Foil on Scrim.	100	100	100
3.	Carbon Black on Dynel.	0	0	0
4.	Aluminum Foil on Paper.	100	100	100
5.	Aluminized Mylar on Sheeting.	100	100	95.5
6.	Vacuum Aluminized Cotton Sheeting.	0	0	0
7.	Swift Cloth (Silver, Parachute nylon)	100	100	100
8.	Milium on Cotton.	0	0	0
9.	Aluminized Coated Nylon.	0	10	67
10.	Aluminized Rubberized Fabric.	0	0	11
11.	Aluminized Mylar Alone	100	94	91
12.	Aluminized Mylar on Paper.	100	100	100

The shelters are designed to provide a high order of thermal insulation, for which purpose a double layer of 1 inch fiber-glass batting will be used. It thus appears, by reference to the data of Table IV, that placing one or two layers of aluminized mylar between the layers of fiber-glass should be effective in reflecting incident radiation. Table V shows data from Pickard and Burns for three different thicknesses of mylar film which had been aluminized and a model of insulating batting containing a double layer of aluminized mylar between a double layer of the fiber-glass. Data were also obtained on double thicknesses of mylar samples alone.

Table V: Microwave Reflectivity of Three Aluminized Mylar Films of Different Thickness and a Model of an Insulating Batting

Sample No.	Description	Percentage of Power Reflected "L" BAND 1,000 mc/s	"S" BAND 3,000 mc/s	"X" BAND 10,000 mc/s
1.	1/4 mil Mylar	100	95	72*
2.	1/2 mil Mylar	100	95	93
3.	1 mil Mylar	100	100	95
4.	Assembled Batting	100	100	95
5.	1/4 mil Mylar - 2 layers	100	95	72*
6.	1/2 mil Mylar - 2 layers	100	95	93
7.	1 mil Mylar - 2 layers	100	100	95

* The low percent of reflectivity of this sample at X-Band is probably due to surface abrasion resulting from excessive flexing and working of the materials and consequent wrinkling, actual reflectance is probably 90 - 95%.

3. Discussion of results

The results of all three series of measurements indicate that rather uniform surfaces of high electrical conductivity have the property of reflecting microwave radiation. In the referenced letter report from Pickard and Burns,[2] Glynn suggests that Samples 5 and 11 exhibit typical results as a function of frequency for materials in which electrical conductivity is slightly less than ideal. Evidently, the conductivity of these samples is less than for Samples 1, 2, 4, 7, and 12 which were reported as having 100% reflectance. He suggests that the particulate nature of the aluminum deposition was such as to produce a small order of non-uniformity of electrical conductance in the surface. The negligible reflectance of samples 3, 6, and 8 are presumably due to an even lower order of continous conduction between small conducting particles (see Table III). The reasons for the "anomalous" behavior of Samples 9 and 10 are not clear but may be due to a degree of continuity intermediate between the "very poor" and the "rather good" (5 and 11). For various "practical" reasons such as cost, availability of materials, comparative ease of handling, resistance of microbial degradation and influence on insulation, a model size shelter was constructed using the fiber-glass/aluminized mylar combination described above. The dimensions of the scale model were 1/4th those of the intended size of the prototypes. This scale model shelter has been submitted for actual field-type testing by Pickard and Burns. The design and construction of this prototype model shelter is described in Part II of this report. Evaluation of the shielding characteristics of this shelter are reported by Pickard and Burns[3] and summarized in Part III.

4. Conclusions

The data presented show that light weight materials are commercially available to enable the engineer to design a shelter which has the desired shielding characteristics. The results of the study show that either aluminized mylar or aluminum foil, either alone or bonded to paper or fabric, meet the electrical requirements. Furthermore, the Swift fabric, silver deposited on a nylon fabric, is also satisfactory.

It is concluded, therefore, that by using any of the above materials, the remaining problems are of design and production. It was for the purpose of considering this aspect that the scale model was constructed and tested.

5. Acknowledgements

The writer wishes to acknowledge the consideralbe assistance he received from many organisations and individuals.

a. For assistance in developing a sufficient fundamental background the writer is indebted to:

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Mr. David Gee, Camouflage Branch, ERDL, Ft. Belvoir, Va.
Mr. G. W. Maltese, Lincoln Laboratories (MIT), Bedford, Mass.
Mr. James J. Glynn, Pickard and Burns, Inc., Needham, Mass.

b. The writer wishes to thank the individuals in various organizations for making the reflectance measurements discussed in this report.

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The writer wishes especially to thank Mr. Frank J. Risso, Chief, Textile Dyeing Laboratory Branch, Textile, Clothing and Footwear Div. for his general guidance in the program and for his helpful comments in preparing the report.

6. References

1. Glynn, J. J. Ltr: Pickard and Burns to QM R&E Command, Subject: Letter Report for Analysis of Pliable Microwave Reflecting Materials Study (P200-32), dated, 24 October 1958.

2. ___________, Ltr: Pickard and Burns to QM R&E Command, Subject: Letter Report for Analysis of Pliable Microwave Reflecting Materials Study (P-200-35), dated, 23 December 1958.

3. ___________, Measurements of Electromagnetic Wave Attenuation Characteristics of Portable Shelters Composed of Pliable Reflecting Materials, P&B Pub. No. 523, Pickard & Burns, 240 Highland Ave., Needham 94, Massachusetts. Prepared for QM R&E Command 15 April 59.

Part II: Description of Test Shelter

Frank O. Johnson Alvin O. Ramsley

1. Introduction

As a result of the findings reported in Part I of this report, a small model of a shelter was constructed for submittal to a field-type test of radio frequency attenuation. The model measured 6 feet in width, 4 feet in height and 6 feet in depth. These dimensions are about one fourth those of one of the shelters under consideration. Aluminized mylar film was used as the reflective element. The previous results indicate this material should provide good shielding and that remaining problems were those of design.

The purpose of this part of the report is to describe the shelter that was submitted to Pickard and Burns Inc., for analysis under Purchase Order C.I. 3093-59M. Preparatory to construction of the test shelter, a conference was held between personnel of the Tentage, Equipage and Parachute Branch and Textile Dyeing Laboratory Branch in order to coordinate construction aspects and electrical requirements. Based on this conference which considered the advice offered by Mr. James J. Glynn of Pickard and Burns during the work described in Part I, the design for preliminary tests was agreed upon.

2. General Design Concepts

The most obvious approach to the solution was the use of a separate, light-weight liner to be suspended inside the thermal insulation barrier. In Part I it was shown that a metallized nylon fabric (Swift Cloth) could function effectively.

An alternate consideration suggested that the electromagnetic shield be incorporated in the thermal shield. It was hoped that adequate shielding could be achieved when the reflective element (aluminized mylar) was inserted between layers of the fiber glass insulation. Furthermore, it was considered that use of a separate liner for the specific purpose of providing electromagnetic shielding would be less economical in cost, weight and bulk storage.

The general design of the prototype submitted for testing was based on use of aluminized mylar included directly as part of the thermal insulation system. In the final shelters it was intended to suspend the combined thermal and electromagnetic barrier within a metal frame. Enclosing the frame and barrier will then be accomplished by a neoprene coated nylon outer layer.

3. Design of combined barrier

The combined barrier included two layers of fiber glass insulation, each 1/2" in thickness. Between these were placed two layers of 1-mil mylar film which had been vacuum aluminized on one side to produce a surface resistance of about 5 ohms per square. In order to minimize abrasion of the effective surfaces, the aluminized surfaces were placed face-to-face, thereby placing the unaluminized surfaces in contact with the fiber glass. A layer of neoprene coated nylon was used to enclose this system. Figure 1 illustrates the arrangement which was used.

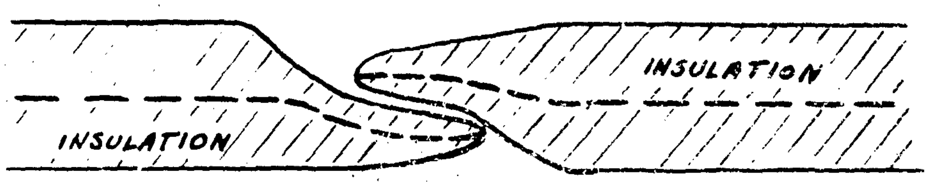
4. Assembly and suspension of barrier

For the prototype shelter submitted for test the barrier was constructed of three pieces. The front end of the shelter was sewn directly to the front half of the side-wall. These two halves were suspended from a tubular aluminum frame with nylon cord through grommets, over-lapping the two halves of the shelter about 1" at the center. This is illustrated in Figure 2.

The bottom edges of the two ends and side panels were carried 12" beyond the floor level and the aprons so formed were turned inward. A ground cloth was placed on the floor and over-lapped the apron from the side wall and ends. In the ground cloth the thermal insulation was omitted, and thus it contained a double layer of aluminized mylar enclosed within an envelope of neoprene coated nylon.

Figure 3 shows the interior of the shelter with the ground cloth in place. From this illustration it is seen that the front end of the shelter was provided with a slide fastener closure. This was necessary for the test only to permit entry of personnel and equipment. In a final design entry will be made through an aluminum door and frame, which in itself should pose no shielding problem.

Preliminary results indicated that an improved closure with better shielding properties was necessary at the center over-lap and at the ground cloth over-lap. Two changes were made in order to improve the design. A beckett closure with a 6" spacing replaced the simple grommet closure, although grommets were still used as suspension points. The other change was to continue the aluminized mylar film out of the insulating bat and fold it over in a manner shown in Figure 4. By these two changes it was hoped that a more continuous reflecting surface could be obtained.



Solid line - Outer Skin

Dashed line - Aluminized Mylar - double layer with aluminum surfaces in contact.

Figure 1: Construction of side-wall bats, first attempt

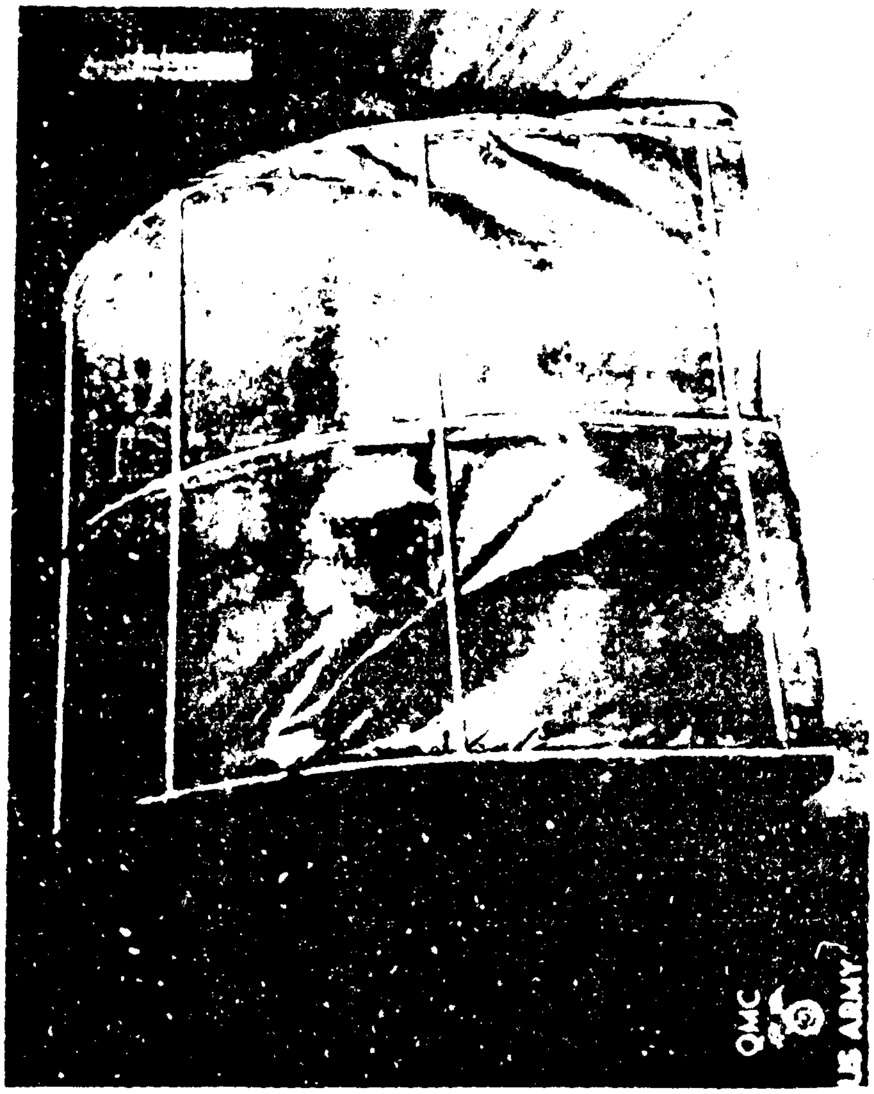
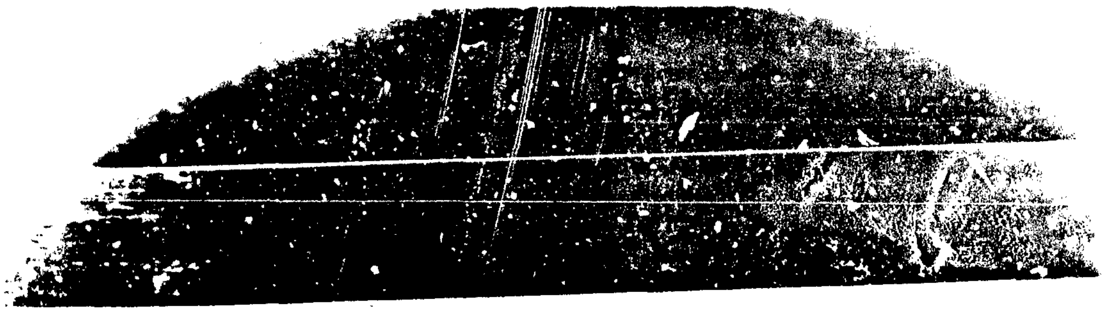


Figure 2: Exterior view of test shelter showing general arrangement and mode of suspension.



Solid line - Outer Skin

Dashed line - Aluminized mylar - double layer with aluminum surfaces in contact

Insulation is not shown

Figure 4: Modified arrangement of layers in test hats.

Part III: Evaluation of Test Shelter

Frank J. Risso   Frank O. Johnson   Alvin O. Ramsley

1. Introduction

The purpose of this part of the report is to evaluate the performance of the test shelter described above in terms of military needs for electromagnetic shielding. It is recognized that the results of the study using the 1/4-scale size test structure can not be translated directly into performance of a full size structure. Thus, a second purpose is to develop those essential aspects which can lead to a recommended design of a full scale model.

2. Summary of Test Results

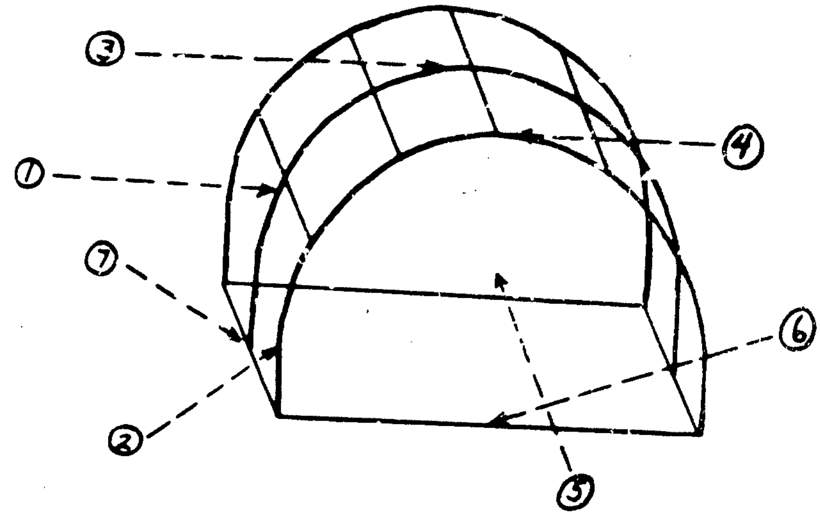
The field study led to the conclusion that adequate shielding is possible with minor changes in construction design. From a materials point of view the aluminized mylar permits attainment of the objectives. Data from the field study show that the ground cover is essential for highest effectiveness.

It was noted that leakage of radio frequency radiation occurred in areas where one section over-lapped another. Leakage was observed at over-lap areas at the center seam and where the ground cloth met the side wall. This indicates that excellent shielding would be provided, if the aluminum surface of the mylar film could be made continuously conducting. However, no leakage was observed in areas where reflecting surfaces were brought into close proximity by a seam seam. In such regions the reflecting surfaces were probably about 1/8" apart. Thus, although absolute electrical continuity might provide assured shielding, it does not appear to be absolutely essential.

The leakage observed at the zippered entry does not apply to the general problem because no such structures would be used in a full scale shelter. An aluminum door and jamb are intended for use as the entry.

Figure 1 illustrates the angles of illumination used. Detectors were placed within the shelter and the probe moved to find the highest reading for a given illumination condition.

Table I summarizes the data obtained for the test condition in which the ground cloth was in place.



LEGEND

1. Horizontal ray directed midway up side at center overlap.
2. Horizontal ray directed at sewn corner.
3. Horizontal ray glancing off center overlap.
4. Horizontal ray glancing off sewn corner.
5. Horizontal ray normal to front at slide fastener.
6. Oblique ray directed down at base of slide fastener.
7. Oblique ray directed down at base of center overlap.

Figure 1: Directions of illumination referred to in Table I.

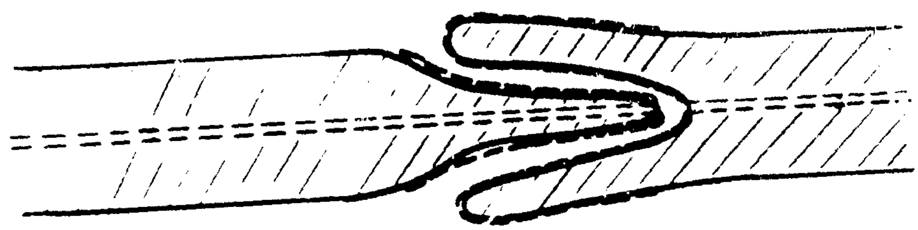
Table I: Attenuation of Microwave Radiation by Test Shelter with Ground Cloth in Place.

Frequency (Mcs)	Test Position	Signal Level at Outer Surface	Signal Level at Inside Shelter	Protection afforded by Shelter	Remarks
1000	1	78.6 db	36.5 db	-42.1 db	AN/APR - 4 Rec.
	2	77.2 db	33.0 db	-44.2 db	Direct Reading
	3	74.5 db	33.0 db	-41.5 db	in DB
	4	75.0 db	34.0 db	-41.0 db	
	5	76.0 db	46.0 db	-30.0 db	
	6	75.0 db	36.0 db	-39.0 db	
	7	79.6 db	38.5 db	-41.1 db	
3000	1	65.0 db	34.0 db	-31.0 db	AN/APR-4 Rec.
	2	58.0 db	22.0 db	-36.0 db	Direct Reading
	3	51.0 db	26.0 db	-25.0 db	in DB
	4	56.0 db	21.0 db	-35.0 db	
	5	73.0 db	38.0 db	-35.0 db	
	[illegible]	73.0 db	43.0 db	-30.0 db	
	7	69.5 db	32.0 db	-37.5 db	
10,000	1	7.0	0.01	-28.45 db	
	2	3.0	0.01	-24.77 db	$DB = 10 \log \frac{P_{MAX}}{P_{MIN}}$
	3	9.7	0.[illegible]	-29.86 db	
	4	30.0	[illegible]	-34.77 db	
	5	90.0	1.00	-19.54 db	PRD Model 60
	6	85.0	0.90	-19.77 db	Bolometer
	7	3.0	0.005	-27.78 db	Amplifier

3. Recommended Design

Financial support was withdrawn before the indicated refinements in design could be made. Therefore, this study will terminate with recommendations for the following changes in design which will improve the shielding effectiveness of the model discussed above. These recommendations are based on a careful review of the results of the experimental work, experience in construction of portable shelters and discussion with electronic engineering personnel of Pickard and Burns.

a. The corrective measures taken to improve the shielding are shown in Figure 4 of the previous part. Although sufficient funds were not available to analyse this change thoroughly, a spot check indicated some slight improvement. The design of the combined thermal and electromagnetic barrier which is now recommended is illustrated in Figure 2. The essential feature is that electrical continuity depends on areas in contact which, in turn, depend on pressures produced by the closure system. The reason for the inadequacy of the design shown in Figure 4 was buckling of the mat and the manner in which the becket lines provided contact pressure.



Solid line - outer skin of batting

Dashed line - aluminized mylar - double layer with aluminum surfaces in contact

Figure 2: Recommended design for batting in areas where sections join.

b. One suggestion for a combined suspension and closure system is shown in Figure 7. The support bands should be made of an appropriate metal (or other material) which would provide constant pressure against the frame.

Adoption of these two techniques should insure that attenuation of at least 40 d.b. would be provided throughout the shelter at L-band frequencies. This compares favorably with attenuation realized by commercial, all metal shielded rooms. The type of closure shown in Figures 6 and 7 would contribute materially to the effeciency of the thermal insulation.

It should be pointed out that the protection afforded by the test shelter is expressed in decibels, a logarithmic unit defined as

$$db = 10 \log \left(\frac{P\ max}{P\ min} \right)$$

Where P is power (maximum outside shelter and minimum inside) in appropriate units. The negative sign indicates a power decrease. In terms of power transmitted a protection of -40 db corresponds to a transmission factor of 0.0001 (0.01%); protection of -30 db corresponds to a transmission factor of 0.001 (0.1%).

In view of the results it may be appropriate to reconsider the alternative approach using a separate lining attached to the inside of the structure after placement of the outer shell and separate insulating bats. Such a liner, made of silver treated fabric (e.g. dynel), would provide adequate shielding with fewer design problems. Since it was shown by Pickard and Burns[1] that an ordinary slide fastener, itself, act as a slot antenna, the tape used in any slide fastener in such a system would have to be metallized in the same manner as the liner proper. A one-piece liner of such design would cost more than use of mylar in the insulating bats; with special slide fasteners the cost would be even higher. Furthermore, a substantial increase in overall weight of a complete shelter would result.

4. **Reference**

1. Glynn, J.J., Measurements of electromagnetic characteristics of portable shelters composed of pliable reflecting materials, Pub. No. Pickard and Burns, 240 Highland Ave., Needham 94, Mass., 15 April 1959.

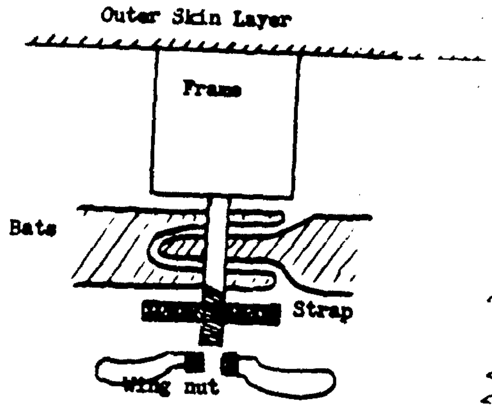


Figure 3: **Suggested method** of attachment of bats with straps.

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